UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
Washington 25, D. C.

REPORT ON THE RECONNAISSANCE SEDIMENTATION SURVEYS OF LOCH RAVEN AND PRETTYBOY RESERVOIRS

BALTIMORE, MARYLAND

By

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Associate Geologist

Special Report No. 5

Sedimentation Section
Office of Research

December 1943

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INTRODUCTION

Reconnaissance sedimentation surveys of Loch Raven and Prettyboy Reservoirs were made October 4-9, 1943, to determine the extent of soil erosion in the Gunpowder Falls watershed and its effect on these downstream storage developments which are part of the water-supply system of Baltimore, Md.

The Bureau of Water Supply of the City of Baltimore supplied maps, a boat, and part-time services of a man to assist in the survey, and their cooperation is gratefully acknowledged. Mr. James Sheetz, assistant soil surveyor of the Soil Conservation Service, assisted in the survey of Loch Raven Reservoir and supplied valuable information relative to watershed conditions.

GENERAL INFORMATION

Location (figures 1 and 2):

State: Maryland.

County: Baltimore.

Distance and direction from nearest city: Loch Raven Dam is located 7 miles northeast of Baltimore City Limits and 5 miles northeast of Towson, Md. Prettyboy Dam is located 18 miles north of Baltimore City Limits and 3 miles northwest of Hereford, Md.

Drainage and backwater: Both reservoirs are located on the Gunpowder Falls. Loch Raven Dam is situated 9 miles above the Gunpowder estuary of the Chesapeake Bay, and Prettyboy Dam is located 12 miles upstream from the head of backwater of Loch Raven Reservoir. The total length of Gunpowder Falls, from head of tidewater to its source in York County, Pa., is about 50 miles. Its principal tributaries are Western Run, which enters the Gunpowder Falls from the west, near the head of Loch Raven Reservoir; Little Falls which enters from the northeast several miles below Prettyboy Dam; and Georges Creek which flows into Prettyboy Reservoir from the west.

Ownership: Bureau of Water Supply, Department of Public Works,

Baltimore, Md.

Purpose served: Municipal water supply.

Description of dams:

Loch Raven Dam is a cyclopean-concrete dam, 650 feet long and 75 feet high above stream bed with a crest thickness of 14-1/2 feet and a thickness at the base of 64 feet. The upstream face is vertical and the downstream face has a slope of 1 foot vertical to 7-7/16 inches horizontal. Elevation of the top of dam is 246 feet above mean sea level, U. S. G. S. datum.

The spillway of Loch Raven Dam is an ogee section located near the center of the dam. It is 288 feet in length, 69 feet above stream bed and has a spillway capacity of 60 cubic feet per second per square mile of drainage. The spillway elevation, when the dam was completed in 1914, was 188 feet above mean sea level. In 1922 the spillway was raised to its present elevation of 240 feet above mean sea level. A 10-foot steel conduit is located at elevation 173.5 in the dam. This conduit extends 4,000 feet to a recently constructed 12-foot concrete tunnel which conveys water by gravity flow a distance of 6-1/2 miles to the Montebello filtration plant.

According to the Bureau of Water Supply the cost of the Loch Raven development, exclusive of engineering cost, was $4,500,508 including the cost of land.

Prettyboy Dam is a concrete gravity overflow dam, 845 feet long and 133 feet high above stream bed. The thickness at crest is 25-1/2 feet and 134 feet at the base. The upstream face is vertical, while the downstream face has a slope of 1 foot vertical to 0.675 foot horizontal. The top of the dam is at elevation 540 feet above mean sea level, U. S. G. S. datum.

The spillway of Prettyboy Dam is a concrete overflow type, 141 feet in height and 274 feet in length. It is located near the east end of the dam. The elevation of the spillway is 520 feet above mean sea level. It was designed for a spillway capacity of 210 cubic feet per second per square mile of drainage. The dam contains two 36-inch needle valve outlets at elevation 421.50 and eight 3- x 5-foot sluice gates near the bottom of the dam.

The cost of Prettyboy Dam, including cost of land, was reported by the Bureau of Water Supply to be $3,973,173.

Dates of completion:

Loch Raven Dam was completed to a height of 56 feet above stream bed in 1914, and was raised to its present height in 1922. Prettyboy Dam was completed in October 1933, but storage began April 10, 1933. At the time of the survey, Loch Raven Reservoir was 29 years old and Prettyboy Reservoir 10.5 years old.

Length of lakes:

Loch Raven Reservoir has a length of 10-1/4 miles, including a mile or more of ponded channel. The length of Prettyboy Reservoir is 7-1/4 miles.

Area of lakes at spillway stage:

The area of Loch Raven Reservoir as determined by this survey from maps supplied by the Bureau of Water Supply is 2,337 acres, and that of Prettyboy Reservoir, 1,571 acres. The area of Loch Raven Reservoir has been reduced a small amount by sediment deposits in the Paper Mill and Ashland Pools. According to the Bureau of Water Supply records, the area of Loch Raven Reservoir is 2,391 acres while that of Prettyboy Reservoir is 1,498 acres.

Storage capacity to spillway level:

	Loch Raven		Prettyboy	
	Acre-feet	M.G.	Acre-feet	M.G
Original..............	65,821	21,448	60,333	19,660
At date of survey......	60,466	19,703	59,764	19,474
Reduction.............	5,355	1,745	569	185

The above capacities were determined by this survey. According to the Bureau of Water Supply, the total original capacity of Loch Raven was 72,733 acre-feet while that of Prettyboy Reservoir was 60,979 acre-feet, or 23,700 M.G. and 19,870 M.G. respectively. It is not known how these estimates were determined since, as reported by the Bureau of Water Supply, no original contour maps were ever made of either Prettyboy or Loch Raven Reservoirs. The difference between the capacity figure given by the Bureau of Water Supply and that determined by this survey for Prettyboy Reservoir is negligible. In the case of Loch Raven Reservoir the difference amounts to approximately 9 percent, which is within the limit of error of the type of survey made. The difference is not necessarily attributable to the present survey, however, but may be due to the lack of large-scale original contour maps from which accurate capacity determinations could be made.

General character of the reservoir basin:

Prettyboy Reservoir is long and narrow, with an irregular shoreline formed by numerous indentations and coves at the entrances of small steep-gradient tributaries. The largest tributary, Georges Creek, forms a long and narrow arm in the lower part of the lake. Water is impounded in a narrow V-shaped valley with steeply sloping valley walls. Residual soils of the steep valley walls are generally very thin, or absent, and the sides and bottom of much of the reservoir are composed of bed-rock. On the more gentle slopes of the wider re-entrants and along the reservoir itself, the bottom is a sticky micaceous, buff-colored, soil material. The gradient of the Gunpowder Falls through Prettyboy Reservoir is 18.4 feet per mile. Pre-reservoir flood-plain deposits were found in limited areas in the lower part of the reservoir and in the Georges Creek arm. In the upper part of the reservoir, above range R28-R27, the reservoir covers an old mill dam. The old millpond deposits, which now form the bottom of the reservoir at this point, are largely gravel.

The shapes of the basins of Prettyboy and Loch Raven Reservoirs are controlled by the structure of the country rock. Prettyboy Reservoir lies entirely within the Wissahickon gneiss and schist formation where stream valleys are narrow and gorge-like. Loch Raven Reservoir, however, extends over a number of rock formations of variable resistance to erosion and, as a result, it is characterized by alternate narrow reaches, broad open bays and numerous irregular arms.

The lower quarter of Loch Raven Reservoir is located in an area of Wissahickon gneiss and schist, which results in a narrow, steep-walled basin similar to that of Prettyboy Reservoir. Above range R4-R3 and extending to range R23-R22 it is underlain by a formation of Cockeysville marble. Broad valleys or lowland meadows have developed in this formation. Where the reservoir has covered these meadows, as above range R4-R3, it broadens out considerably and has very gentle valley slopes. Above range R23-R22 to the head of the lake the predominant rock formations are Wissahickon schist and Baltimore gneiss, which form narrow, steep-walled channels. A narrow belt of Cockeysville marble crosses under the reservoir at a point about a mile below the head of

backwater and forms the so-called Paper Mill Pool. Its counterpart on Western Run is known as the Ashland Pool. The gradient of the Gunpowder from the head of backwater to the dam is 6.7 feet per mile, only a third of that at Prettyboy Reservoir.

Area of drainage basin:

According to the Bureau of Water Supply, the drainage area of Loch Raven Reservoir extends over 303 square miles, while that of Prettyboy Reservoir is 80 square miles.

General character of the drainage basin:

Geology.--The drainage basin of Loch Raven and Prettyboy Reservoirs lies entirely within the eastern division of the Piedmont Plateau province. The rocks of the drainage area are largely highly crystalline pre-Cambrian metamorphics of the Clenarm series, which have been folded into a series of anticlinal domes trending from southwest to northeast in a direction normal to the direction of the major axis of the watershed. The oldest rock in the watershed is the Baltimore gneiss of early pre-Cambrian age. Overlying the Baltimore gneiss unconformably is the Setters formation. Cockeysville marble overlies the Setters formation and in turn is overlain by the Wissahickon formation, and the Peters Creek formation. The Setters formation consists of a series of gneisses, quartzites, and mica schists, and the Cockeysville is a coarse white dolomitic marble. The Wissahickon formation in the southeastern part of the drainage area is an oligoclase-mica schist, while in the northwestern portion it consists of an albite-chlorite schist. Peters Creek formation consists of mica schist, quartzite and gneiss. An igneous intrusion of Gunpowder granite occurs just west of Loch Raven Reservoir midway between the dam and head of backwater.

The Baltimore gneiss forms the core of an anticlinal fold in the lower part of the watershed, just above the head of backwater of Loch Raven Reservoir. The Setters formation occurs as a narrow belt surrounding this anticline and is also found on the margins of the intrusive Gunpowder granite. Cockeysville marble outcrops in narrow belts along the rims and noses of anticlines and as outliers on the Baltimore gneiss. A more general areal distribution of the Cockeysville marble is found between the southeastern margin of the Baltimore gneiss and the Loch Raven Dam. In this area it has been folded into a wide shallow syncline which has been intruded by the Gunpowder granite. Overlying the Cockeysville marble in this syncline is the oligoclase-mica schist phase of the Wissahickon formation, which also outcrops in a broad belt northwest of the Baltimore gneiss. The Peters Creek formation outcrops in a broad belt in a syncline of the Wissahickon formation northwest of the core of Baltimore gneiss but it is not known to occur southeast of this outcrop in the Gunpowder Falls watershed. The watershed of Prettyboy Reservoir lies entirely in the albite-chlorite schist phase of the Wissahickon formation.

Soils.--The complex geological arrangement of rock types in the Gunpowder Falls watershed has given rise to equally complex soil types. There are two major groups of soils in the watershed, the residual soils

formed through weathering of underlying rocks, and the alluvial soils found along stream bottoms. The weathering of the crystalline rocks produces soils of the Chester and Manor series, and the weathering of Cockeysville marble produces Hagerstown soils. The alluvial soils comprise the Congaree series.

The most extensive soil types in the Gunpowder watershed are the Manor loam and Chester loam which occur in large areas on the gently rolling to hilly upland. They are friable, generally micaceous, brown to yellowish soils. Along the steep valley walls of the Gunpowder Falls and the larger tributaries above Prettyboy Dam, the Manor and Chester soils are shallow and contain fragments of bedrock. The Hagerstown loam, formed by weathering of the Cockeysville marble, occupies irregular areas in the limestone valleys in the lower part or the watershed. These valleys are from 1/4 to 3 miles wide and are usually connected. The Congaree, or alluvial soils are relatively unimportant in the Gunpowder Falls watershed because of their limited extent in the narrow gorge-like valleys.

Topography and drainage.--The topographic features of the Gunpowder Falls watershed may be divided into three distinct types: The summit uplands, the narrow gorge-like valleys, and the wide meadow lowlands. The summit uplands are dissected peneplains which are usually gently rolling to rolling. They furnish the most extensively cultivated land of the watershed. The slopes of the upland summits break off abruptly to form narrow, steep-walled gorges of the main Gunpowder Falls and principal tributaries. The topography is one of maturity affected by uplift, which started a new cycle of geologic erosion. The narrow winding valleys are usually well wooded and not cultivated. The wide meadow lowlands are gently rolling, and were formed by removal of Cockeysville marble in solution. They occur only in the lower part of the drainage basin, and their surfaces are generally 100 feet below the level of the summit uplands. The meadow lowlands are generally intensively cultivated but they occupy only a small part of the total area of the watershed.

The drainage system of the watershed is well developed and follows a dendritic pattern. The Gunpowder Falls flows in a well-defined, deep and narrow valley with a fairly high stream gradient. The tributaries which drain areas underlain by crystalline rocks are usually relatively short with high gradients. Streams flowing through limestone valleys are much longer and have considerably smaller gradients than those in crystalline areas. The limestone valleys through which they flow are usually narrow, and the minor tributaries, therefore, have their sources in crystalline rocks so that they are short and have steep gradients in contrast to the main streams into which they empty.

Erosion conditions.--The greater part of the Gunpowder Falls watershed is, or originally was, cultivable. It is composed mainly of soils of the Chester and Manor series which, although originally fertile, are loose and friable and erode rapidly when plant cover is removed or when cultivated without erosion control practices on slopes of more than 2 or 3 percent.

Erosion has been active throughout the area. Generally the steep slopes of the drainage ways are well wooded and under these conditions only very slow normal geologic erosion occurs. When these slopes are cleared, however, usually by extending fields on the summit uplands too far down the valley sides, the slopes erode badly.

Severe sheet erosion is active on the cultivated summit uplands and has removed much of the fertile topsoil, as indicated by accumulations of colluvial deposits, in some cases amounting to several feet in thickness, below steeper slopes. Severe sheet erosion of the summit uplands is an important land problem confronting the farmers of the Gunpowder Falls watershed today and has been for 150 years.

Occasional gulleying is evident in certain parts of the drainage area and, although some material is carried into the streams by this process, it is not believed to be as important as sheet erosion. Roadside erosion occurs to some extent along secondary roads but the amount of material derived from this source is unimportant compared to the amount derived from sheet erosion. Roadside erosion was probably more severe in the past than at present, for deep cuts exist where formerly unsurfaced roads crossed the crests of steeper hills or extended down the steep slopes of stream valleys. In general, the greatest amount of sediment in Loch Raven and Prettyboy Reservoirs is derived from sheet erosion of cultivated summit uplands.

Land use.--No surveys to determine land use in the Gunpowder Falls watershed were made during this survey. It was reported in 1911 that as much as 85 percent of the watershed was in cultivation or without tree covering of any kind.1/ A very large part of the Gunpowder Falls watershed is in farms. Since much of the Gunpowder Falls watershed above Loch Raven dam is in Baltimore County, it is believed that the land use figures given in the 1940 census of agriculture of this county are representative of the land use in the Gunpowder Falls watershed. According to the 1940 census, land use on farms in Baltimore County was as follows:

	Percent
Cropland	42.4
Cropland, idle or fallow	9.7
Plowable pasture	13.4
Woodland	23.1
Other	11.4
	100.0

Market gardening is the principal type of agriculture in the watershed in the vicinity of Baltimore and general farming and dairy farming, sometimes in conjunction with market gardening, predominates throughout the rest of the watershed. The 1940 census showed that

1/ Baltimore City-Wide Congress. Report of the Committee on Forestation of Watersheds, p. 5, December 16, 1911.

the principal crops grown in Baltimore County by acreage were: hay 34,493 acres; corn 22,024 acres; wheat 14,446 acres; and vegetables 13,951 acres. There was a notable decline in acreage of vegetables from 1934 to 1939. In 1934 there was a total of 21,191 acres in vegetables and the market value of the produce was $2,236,059, but by 1939 this area dropped to 13,951 acres with a value of only $981,918. This decrease is due in part to the fact that vegetables produced by southern growers reach the Baltimore markets before crops in this vicinity can be harvested. The census figures show that there has been a slight decrease in acreage of cropland harvested but that there has been an increase in acreage of plowable pasture, indicating a general shift toward dairy farming.

Mean annual rainfall:

The mean annual rainfall at Loch Raven Reservoir is 42.53 inches and at Prettyboy Reservoir 42 inches. Over 55 percent of the rainfall occurs during the spring and summer seasons. Occasionally there are periods of many days with little or no precipitation. In 1884, for example, there was a period of 51 days when the total precipitation amounted to only 0.39 inch. In 1943, for a period of 105 days, from July 12th to October 25th, no single rainfall exceeded 0.66 inch. A rainfall of 0.66 inch probably would not contribute appreciable surface runoff.

History of storage:

Prettyboy Reservoir is used as a regulating reservoir for Loch Raven Reservoir. During the summer months of high water consumption, Loch Raven Reservoir is usually drawn down to about 3 feet below crest, and the water surface is maintained at this elevation by releasing water from Prettyboy Reservoir. During prolonged dry periods, such as occured just prior to this survey, Prettyboy Reservoir may be drawn down as much as 10 or 15 feet below crest. Water usually flows over the spillway of Loch Raven Dam nine months out of the year while the water at Prettyboy Reservoir has always been at crest level except when it was drawn on for the first time in September 1941 and again this year. The average daily flow of the Gunpowder Falls at Loch Raven Reservoir is estimated to be 270 million gallons per day. The average daily water consumption for 1943 was 165.1 million gallons per day.

Water consumption for the City of Baltimore and environs has increased markedly since 1938 due to: (1) an increased demand by new industrial plants for war production, (2) failure of the private industrial underground water supply, and (3) increase in area and population served. During the month of August 1943, consumption for the City of Baltimore amounted to 183.4 million gallons per day, an all-time high, and would have gone still higher if restrictions, which saved from 10 to 15 million gallons per day, had not been placed on the use of water. Table 1 gives the population served and the average daily consumption of water for the period 1938-43.

Table 1.--Population served and average daily water consumption, Baltimore, Md., from 1938 to 1943

Year	Population served	Average daily water consumption in million gallons
1938......................	931,000	115.9
1939......................	937,500	123.7
1940......................	966,200	129.2
1941......................	1,007,000	137.0
1942......................	1,125,000	148.9
1943......................	1,178,400	165.1

METHOD OF SURVEY

The original capacity and sediment volume in both Loch Raven and Prettyboy Reservoirs was determined by the range method. Eighteen ranges were used for measurements of water depths and sediment thickness on Loch Raven Reservoir and 14 on Prettyboy Reservoir (see figures 1 and 2). Direct measurements of sediment and water depths were made simultaneously at regular estimated intervals along these ranges, using a sectional sampling spud attached to a sounding line upon which the depth of water could be read directly. A total of 123 observations were made on Loch Raven Reservoir and 84 on Prettyboy Reservoir, including spot measurements in bays..

The water and sediment depths for each range were plotted on cross-sectional paper and the respective areas of each determined by planimetering. The volume of water and the volume of sediment was then determined by the following formula:

$$V = \frac{A'}{3}\left(\frac{E_1 + E_2}{W_1 + W_2}\right) + \left(\frac{A}{3}\,\frac{E_1}{W_1} + \frac{E_2}{W_2}\right) + \frac{h_3E_3 + h_4E_4 + \text{---}}{130{,}680}$$

where: V = Original capacity or sediment volume, in acre-feet

A' = The quadrilateral area in acres formed by connecting points of range intersection with crest contour between ranges

A = The lake area of the segment, in acres

E = The cross-sectional area, in square feet

W = Length of bounding range at crest elevation, in feet

h = The perpendicular distance from the range on a tributary to the junction of the tributary with the main stream or to a point where the thalweg of the tributary intersects the downstream range.

The original capacity and sediment volume for the segment next to the dam was computed by the formula $V = A \frac{E}{W} - V_o$, where V, A, E, and W are the same as above and V_o is the volume displaced by the upstream face of the dam. Since the upstream face of Loch Raven Dam and Prettyboy Dam is vertical, $V_o = 0$.

It was found that the distribution of sediment in smaller re-entrants was irregular, so that the range method of calculation of the sediment volume was unsatisfactory. Consequently, spot measurements of sediment thicknesses and water depths were made in these areas and the original capacity and sediment volume was determined by the average depth method which is expressed by the following formula:

$$V = \frac{SA}{n + 1}$$

where V = The volume of original capacity or sediment, in acre-feet.

S = Sum of the individual water-depth or sediment-depth measurements, in feet.

A = Surface area of the re-entrant, in acres.

n = Number of observations.

The results of a reconnaissance-type reservoir survey such as was made on Prettyboy and Loch Raven Reservoir are not comparable in accuracy to the results obtained by detailed surveys with instrumental control. However, they afford a rapid means of estimating the approximate rate of silting of reservoirs and the results are sufficiently
mate rate of silting of reservoirs and the results are sufficiently
reliable to indicate whether the useful life of the reservoir is of the order of tens, scores or hundreds of years. In the majority of cases, where reconnaissance surveys have been followed up with detailed surveys, it has been found that the results of the reconnaissance-type survey are within 10 percent of those of the detailed survey. It is believed that the survey of Prettyboy Reservoir is relatively more accurate than that of Loch Raven Reservoir because in every measurement of sediment in Prettyboy Reservoir it was possible to completely penetrate the sediment to the reservoir bottom. In several instances in Loch Raven Reservoir, complete penetration of the delta deposits was not accomplished.

SEDIMENT DEPOSITS

Character of Sediment

The contact between the lake deposits and the underlying submerged basin materials was generally easily recognized in Prettyboy Reservoir. In the lower section of this reservoir the bottom is bedrock and, except in the old stream channel, no sediment was found. In and adjacent to the main channel there is a deposit of very fine to fine-grained sand up to 2 feet in depth which contains rootlets, seeds, bark scalings and grass. This material was interpreted to be of pre-reservoir origin, probably flood-plain and channel deposits. Original

soil on the reservoir bottom was found to be brown in color, sticky and tenaceous, containing fragments of undecomposed rock. When the spud penetrated deeply into this old soil, it was extracted with considerable difficulty. The sediment deposits in Prettyboy Reservoir are decidedly less compact than the old soil and are lighter in color. The silt has a loose slippery, greasy feeling, while the old soil has a gritty texture when rubbed between the fingers.

Identification of the contact between the sediment deposit and underlying reservoir bottom was much more difficult in Loch Raven Reservoir than in Prettyboy Reservoir for several reasons. Underlying the sediment deposits in Loch Raven Reservoir there are two main deltas, one in the lower part of the lake which developed in Old Loch Raven Reservoir, which was created by a dam constructed 3/4 of a mile below the present dam, and a second delta deposit which was formed during the period 1914-1922 when the present dam had a lower crest elevation. The presence of distinctly different types of soils underlying the reservoir also gives a variation in the nature of bottom materials.

In the lower part of the reservoir, the sediment is underlain by a light-colored, sandy micaceous silt loam, presumably the delta deposits of Old Loch Raven. The side slopes, above the crest elevation of Old Loch Raven Reservoir, and the reservoir bottom along range R3-R4, are composed of very compact buff-colored, sticky original soil containing rock fragments. Along range R5-R6 the bottom material was sandy, probably representing the delta deposit of Dulaney Valley Branch at the 1914-1922 crest elevation. In the areas underlain by Cockeysville marble, the submerged soil was found to be a very compact, sticky, red clay which adheres tenaceously to the spud. Much of the upper part of the reservoir is rock bottom with exception of those areas underlain by Cockeysville marble. It was not possible to obtain complete penetration along range R27-R26 which may have been due to delta deposits of the 1914-1922 period. Sand bottom was found by boring along range R29-30 and probably represents pre-reservoir flood-plain material.

The silt in Loch Raven Reservoir is light-colored and dries to a fine grayish-white powder. Although it is smooth to the touch, it does not seem to have the slippery, greasy feel characteristic of the silt in Prettyboy Reservoir. Very fine flecks of mica are visible in sunlight. The sediment at the heads of the larger bays and in the delta deposits, including the submerged deltas formed from 1914-1922, is usually sandy. The sediment in these deposits has been exposed to repeated wetting and drying, and consequently is very compact. Large accumulations of leaves were found in the sediment in the main body of the reservoir from the junction of Western Run to the head of Paper Mill Pool. An accumulation of leaves was exposed in a vertical section in Paper Mill Pool by erosion due to the drawdown prior to this survey. Examination showed a compact lenticular mass with a maximum thickness of nearly 3 feet. There seemed to be no difference in the state of decomposition of the leaves in lower part of the section from those in the upper part, indicating that they probably deposited in this mass in a single season.

The sediment in Paper Mill Pool was found to be vesiculated due to the escape of carbon dioxide, methane, or other gases generated by the decay of organic matter. The diameter of some vesicules measured up to 6 inches and had an apparent depth of several feet. The deposit around the perimeter of these vesicules was several inches higher than the prevailing level of the deposits in which they were formed and the vesicules resembled animal burrows. The largest vesicules seemed to be forming in a zone of submerged deposits adjacent to exposed natural levees parallel to the main channel of the Gunpowder Falls.

Gas bubbles were observed to be rising continuously from the submerged deposits throughout the reservoir above Western Run and a violent stream of bubbles rose to the surface each time the spud penetrated the deposits and released quantities of trapped gases.

Distribution of Sediment

No sediment was found in the main body of Prettyboy Reservoir below range R22-R21. Along range R22-R21 a maximum depth of only 0.7 foot was found but above this range there is a progressive increase of sediment depths to the head of the reservoir. A maximum depth of 6.0 feet of sediment was found on range R29-R30 which had an average sediment depth of 3.3 feet.

The distribution of sediment in the arms formed by the major tributaries is similar to that of the main reservoir. Thus, in the Georges Creek arm, the largest tributary to the reservoir, no sediment was found below range R11-R10 where a maximum depth of only 0.4 foot sediment was found. Sediment thicknesses increased progressively upstream toward the head of the arm where a maximum depth of 3.3 feet was found. The average depth of sediment along range R12-R13 was 2.4 feet. The longitudinal distribution of sediment in Prettyboy Reservoir is shown in figure 3.

The sediment in Prettyboy Reservoir has been redistributed to some extent by drawdown in 1941 and 1943. In this way the sediment deposited near the head of the reservoir while the water surface of the reservoir was at spillway elevation, was eroded and redeposited farther down the reservoir during the dry seasons when the water surface dropped below spillway elevation due to release of water through the dam. Wave action at various water levels has cut numerous step-like terraces in the thin soil mantle of the steep banks along the shores. These terraces indicate that wave-eroded bank material is not moved very far from its source, even on the steeper slopes. Because the reservoir is narrow and winding the wind generally does not obtain long sweeps and consequently, wave action is not as pronounced on Prettyboy Reservoir as it is on Loch Raven Reservoir. Wave deposited material was not included in the measurement of sediment in Prettyboy Reservoir because it does not represent a storage loss so long as the erosion occurs below crest elevation. Because thin soils generally overlie resistant rock slopes, only minor amounts of sediment in the reservoir are derived from shore erosion above crest elevation.

The distribution of sediment in Loch Raven Reservoir differs distinctly from that in Prettyboy Reservoir because of a difference in storage history and because of the difference in shape of the reservoir basin. Delta deposits of Old Loch Raven Reservoir were recognized along range R2-R1 just above the present dam and delta deposits which formed in New Loch Raven Reservoir during the period 1914-1922 were recognized in Dulaney Valley Branch and along ranges R25-R24 and R27-R26 where maximum depths of sediment of 10.0 and 9.0 feet, respectively, were found without penetrating to old soil or rock bottom.

The shape of Loch Raven Reservoir has played an important part in the distribution of sediment. The reservoir near the head, and the Western Run arm, widen appreciably from narrow confined channels to form the Ashland and Paper Mill Pools. These pools form natural settling basins which are both nearly filled with sediment. The deposits in both pools have been built up in places to a foot or more above crest elevation especially adjacent to their main channels. In the Paper Mill Pool sizable above-crest islands have formed. These have been taken over in most instances by vegetation, principally willows. Natural levees have formed adjacent to the main channel of the Gunpowder Falls for the entire length of the pool, a distance of about 1,200 feet. In the upper end of the pool, the levees are exposed a foot or more above crest, but at the lower end they are submerged so that the depth of water over them at Paper Mill Bridge is about 6 inches. The sediment in both pools is very compact due to aeration. It is estimated that about 25 percent of the total sediment in Loch Raven Reservoir has been deposited in the Paper Mill Pool.

The distribution of sediment in coves is unusual. It is brought in by two agents, the small stream which enters at the head of the cove and the reservoir water itself. As a result there is a point of maximum deposition at the head of the cove and another where the cove widens into the reservoir proper. Between these two points there is an area of least deposition. There is a progressive migration of both deposits toward the area of least deposition and the location of this point in each cove is a function of the size of the drainage area of the stream entering the cove and the position of the cove in respect to the reservoir; that is, the coves near the head of the reservoir receive more sediment from the reservoir itself than do those farther downstream.

The longitudinal distribution of sediment in Loch Raven Reservoir is shown in figure 4. It may be seen from this graph that the average depth of sediment increases progressively toward the head of the reservoir. Unlike Prettyboy Reservoir, the sediment in Loch Raven Reservoir extends down to the dam. The side slopes of the reservoir are generally clean. Maximum depths of sediment were found in the channels.

Due to repeated drawdown of the reservoir, slight bank erosion has taken place along the perimeter of the reservoir. On steep slopes, with thin soils, bank erosion is unimportant because wave action is not effective in cutting the bedrock and only a thin layer of soil is removed. Wave action is most severe adjacent to the wide areas underlain by Cockeysville marble for on these areas the wind has a wide sweep and wave action is con-

sequently much more active than in the narrow confined channels of the reservoir. The slope of the banks adjacent to these wide areas is gentle and the waves roll in to cut considerable volumes of soil from the banks. This material is generally not transported very far but is dropped in the vicinity of the cut banks. Wave action was found to be most severe along the eastern shore of the reservoir, opposite the widest part of the lake, where waves have cut out a foot or more of the banks. Bank cutting below crest elevation is unimportant so far as loss of storage is concerned because for every unit volume of storage lost in the reservoir by this means there is an equal unit of storage gained along the bank. The cutting of material from above-crest elevation, however, means a storage loss which is not compensated by a storage gain. In Loch Raven Reservoir, there has been only a minor amount of bank cutting above crest and, therefore, loss of storage by bank cutting has been negligible.

Delta features:

Both Prettyboy and Loch Raven Reservoirs have channel-type conditions at the head of backwater. Unlike many reservoirs, true deltas have not formed at the head of backwater. At Prettyboy Reservoir, the heavier particles are dropped in the channel near the head of backwater mainly at flood stage and this material is reworked as the water surface drops. There is an absence of true foreset beds of a delta front.

In Loch Raven Reservoir, the conditions are somewhat different in that the wide pools on the Western Run and in Gunpowder Falls create conditions conducive to delta formation. The heavier particles accumulating in channels above these pools during normal flow are swept into the pools during flood flows, but the stilling effect of the pools tends to trap most of the coarser material. Thus, the deposits in these pools are delta deposits interbedded with silt which is deposited during normal runoff. The above-crest deposits in the pools are typical delta deposits. The narrow ponded channels of Loch Raven and Prettyboy Reservoirs are filled with sediment to the extent that only the normal cross sections of the streams remain.

Mode of distribution:

From the character and distribution of sediment in both reservoirs it is evident that the principal agent of distribution of sediment is current action caused by inflow. The absence of silt deposits in the lower part of Prettyboy Reservoir indicates that sediment in the inflow settles out fairly rapidly, that is, within a distance of about 2 miles from the head of the reservoir. There is no positive evidence to indicate that density flows reach Prettyboy Dam.

There is evidence that density flows occur occasionally at Loch Raven Reservoir and these undoubtedly have had some effect on the distribution of sediment in the reservoir. During this survey several rains occurred which developed turbid inflows. The writer observed several of these from an excellent vantage point on the Paper Mill

bridge which crosses the reservoir just below the Paper Mill Pool. The flow of the Gunpowder Falls, was observed to follow the main channel of the reservoir and was joined at this point by the turbid flow of Greens Branch, a tributary which enters the Gunpowder Falls just above Paper Mill bridge. Greens Branch drains an area largely underlain by Cockeysville marble and the turbid flow from this stream was distinctly darker in color than that of the Gunpowder Falls. The two did not mix readily but moved down the reservoir channel, side by side, as a single flow, with each retaining its individual identity. For a mile or more below the bridge, the outer margins of the flow could be traced on the surface by two parallel continuous trails of floating, becalmed leaves. Between these trails only an occasional leaf or piece of driftwood was observed on the surface. It was found that the top of this flow formed a safe avenue of travel with a motorboat because it was relatively free of drift. Outside of the leaf trails, logs up to 8 inches in diameter were becalmed. No plunge point was observed and it was not ascertained whether the flow actually reached the dam. The density flow seemed to be more of an overflow than an underflow which may have been due to the fact that the inflow, caused by a warm rain, had a lower density than the colder reservoir water.

CONCLUSIONS AND RECOMMENDATIONS

A summary of data of this survey is given in the tabulations on pages 16, 17, and 18. The results show that the rate of sediment production per unit area of drainage is somewhat higher for the area above Prettyboy Reservoir than for the total drainage area of Loch Raven Reservoir. The average annual rate of sediment production per acre of drainage above Loch Raven Reservoir was found to be 42.0 cubic feet while the corresponding rate above Prettyboy Reservoir was 47.6.

The construction of Prettyboy Reservoir above Loch Raven Reservoir has reduced the sediment inflow to Loch Raven Reservoir during the past 10 years. If the amount of sediment deposited in Prettyboy Reservoir is added to that found in Loch Raven Reservoir for this period, the average sediment production for the entire watershed above Loch Raven Reservoir, including that of Prettyboy Reservoir, is 46.4 cubic feet per acre as compared to 47.8 for the area above Prettyboy Reservoir alone. The difference is small and well within the limits of survey error.

The annual rate of storage depletion was found to be 0.3 percent for Loch Raven Reservoir and 0.1 percent for Prettyboy Reservoir. This difference is due primarily to the difference between the capacity-watershed ratios of the two reservoirs. Prettyboy Reservoir has an extremely high capacity-watershed ratio equal to 754 acre-feet per square mile of drainage, whereas Loch Raven Reservoir has a capacity-watershed ratio of only 217 acre-feet per square mile. With the same sediment production from the drainage area, all other conditions remaining equal, the rate of storage depletion of Loch Raven Reservoir would be about three times that of Prettyboy Reservoir.

Summary of data on Loch Raven Reservoir, Baltimore, Md.

	Quantity	Unit
Age[1]	29	Years
Watershed area[2]	303	Square miles
Watershed area[3]	299.4	Square miles
Reservoir:		
Area at spillway stage:		
Original	2,337	Acres
At date of survey	--	Acres
Storage capacity at crest level:		
Original	65,821	Acre-feet
At date of survey	60,466	Acre-feet
Capacity per square mile of drainage area:[2]		
Original	217.2	Acre-feet
At date of survey	199.6	Acre-feet
Sedimentation:		
Total sediment	5,355	Acre-feet
Average annual accumulation:		
From entire drainage area	184.7	Acre-feet
Per 100 square miles of drainage area[3]	61.7	Acre-feet
Per acre of drainage area:[3]		
By volume	42.0	Cubic feet
By weight[5]	1.26	Tons
Depletion of storage:		
Loss of original capacity:		
Per year	0.3	Percent
To date of survey	8.1	Percent

[1]Storage began 1914; average date of survey October 5, 1943.

[2]Including area of lake.

[3]Excluding area of lake.

[4]Excluding above-crest deposits.

[5]Based on assumed dry weight of 60 pounds per cubic foot.

Summary of data on Prettyboy Reservior, Baltimore, Md.

	Quantity	Unit
Age[1]	10.5	Years
Watershed area[2]	80	Square miles
Watershed area[3]	77.5	Square miles
Reservoir:		
Area at spillway stage:		
Original	1,571	Acres
At date of survey	1,571	Acres
Storage capacity at crest level:		
Original	60,333	Acre-feet
At date of survey	59,764	Acre-feet
Capacity per square mile of drainage area:[2]		
Original	754.2	Acre-feet
At date of survey	747.1	Acre-feet
Sedimentation:		
Total sediment	569	Acre-feet
Average annual accumulation:		
From entire drainage area	54.2	Acre-feet
Per 100 square miles of drainage area	69.9	Acre-feet
Per acre of drainage area:[3]		
By volume	47.6	Cubic feet
By weight[4]	1.43	Tons
Depletion of storage:		
Loss of original capacity:		
Per year	0.1	Percent
To date of survey	0.9	Percent

[1] Storage began April 19, 1933; average date of survey October 6, 1943.

[2] Including area of lake.

[3] Excluding area of lake.

[4] Based on assumed dry weight of 60 pounds per cubic foot.

Summary of net erosion from Gunpowder Falls Watershed above Loch Raven Dam, Baltimore, Md.

	Quantity	Unit
Period[1]	29	Years
Watershed area[2]	299.4	Square miles
Total sediment[3]	5,924	Acre-feet
Average annual accumulation:		
From entire drainage area	204.3	Acre-feet
Per 100 square miles of drainage area[2]	68.2	Acre-feet
Per acre of drainage area:[2]		
By volume	46.4	Cubic feet
By weight[4]	1.39	Tons

[1]Age of Loch Raven Reservoir.

[2]Exclusive of the area of Loch Raven Reservoir.

[3]Does not include above-crest deposits at Loch Raven Reservoir.

[4]Based on assumed dry weight of 60 pounds per cubic foot.

The net drainage area of Loch Raven Reservoir, exclusive of the lake area and of the area above Prettyboy Dam, is 219 square miles. If the future sediment inflow from these 219 square miles continues to be on the order of 46.4 cubic feet per acre, it will take 344 years for the remaining capacity of the reservoir to be reduced to normal channel conditions of the Gunpowder Falls, assuming that the volume of the normal channel of the stream is equal to 15 percent of the remaining reservoir capacity. At a rate of sediment production of 47.6 cubic feet per acre annually, it will take 937 years for Prettyboy Reservoir to be filled to channel conditions of the Gunpowder Falls.

A number of sedimentation surveys have been made in Maryland, Virginia, and Pennsylvania to determine the rate of silting of reservoirs and the extent of erosion in their watersheds. The results of these surveys, together with the results of the Prettyboy and Loch Raven surveys, are summarized in Table 2 which shows that the rate of sediment production in the Gunpowder Falls watershed is higher than any rate yet found in these three states. Although Palington Reservoir in Pennsylvania has a rate higher than that of Loch Raven, it is based on such a short period of observation that it is hardly comparable. In comparison with sediment production rates of watersheds of equal size in the Southern Piedmont area, where soil erosion is considered a major problem, the rate of the Gunpowder Falls watershed ranks above the mean for this area.

As pointed out previously in this report, the main source of sediment deposited in Loch Raven and Prettyboy Reservoirs is sheet erosion of cultivated land. It has been demonstrated in other areas of the country that the use of approved soil conservation measures is capable of materially reducing the volume of sediment delivered to streams. In the case of the Gunpowder Falls watershed there is no doubt but that such measures would greatly improve crop production as well as reduce the rate of sediment inflow to Prettyboy and Loch Raven Reservoirs. Such a program is urgently needed, would unquestionably pay for itself, and would be of mutual benefit to the City of Baltimore and the landowners.

The City of Baltimore has purchased, in connection with the Prettyboy and Loch Raven developments, a total of 15,461 acres of land at a cost of nearly $3,500,000. About 3,900 acres are flooded by the reservoirs, leaving some 11,500 acres adjacent to the reservoirs which are subject to erosion. Most of this land has been taken out of cultivation by the city and much of it has been improved and protected from erosion by a commendable program of reforestation. Although this is a step in the right direction, the area of land owned by the City amounts to only 6 percent of the total area of

Table 2.--Estimated sediment production rates based on surveys of reservoirs in Maryland, Virginia, and Pennsylvania

Name of reservoir	State	Location	Age at date of survey	Original capacity	Watershed area	Capacity: watershed ratio	Annual storage loss	Sediment[1/] production
			Years	Acre-feet	Sq. miles	Acre-feet	Percent	Cu.ft./acre/yr.
PRETTYBOY	Maryland	Baltimore	10.5	60,333	80	778	0.1	47.6
Palington	Pennsylvania	Spring Grove	1.6	63	2.91	22	3.03	45.55
LOCH RAVEN	Maryland	Baltimore	29	65,821	303	217	.3	42.0
New Glatfelter	Pennsylvania	York	2	62	3.0	21	2.85	40.27
Hinckston Run	Pennsylvania	Johnstown	32	3,453	10.75	321	.13	27.30
Williams	Pennsylvania	York	27	2,686	42.9	63	.63	26.68
Quehmahoning	Pennsylvania	Johnstown	25	35,295	92	384	.10	26.16
Burnt Mills	Maryland	Silver Spring	7.8	170	27	6	5.96	25.53
Barcroft	Virginia	Alexandria	23.1	1,847	14.5	127	.20	17.49
Griffen	Pennsylvania	Scranton	53	1,991	3.21	620	.04	15.2
Salt Lick	Pennsylvania	Johnstown	23	2,492	11.86	210	.09	14.97
New River Reservoirs (4)	Virginia	Byllesby	33.5	13,255	1,320	----	1.84	12.56
Edgemont	Maryland	Hagerstown	35.5	294	2.5	118	.13	10.74
Whyel	Pennsylvania	Uniontown	20	60	1.3	46	.30	10.47
Gorley	Pennsylvania	Uniontown	30	150	3.0	50	.26	9.08
Pedlar	Virginia	Lynchburg	31	1,860	33.08	56	.24	9.08
Bridgeport	Pennsylvania	Mt. Pleasant	50	612	32.5	19	.52	6.66
Indian Creek	Pennsylvania	Connellsville	32	770	109.6	7	1.09	5.24
No. 7	Pennsylvania	Scranton	69	376	13	29	.24	4.6
Gordon	Maryland	Cumberland	26.6	3,129	64	49	.12	4.12
Koon	Maryland	Cumberland	8.2	7,312	60	122	.04	3.60
Piney	Pennsylvania	Clarion	13	2/27,000	2/980	28	.14	2.60
Elmhurst	Pennsylvania	Scranton	51	3,746	34.85	107	.03	2.3
Staunton	Virginia	Harrisonburg	14	385	24.95	15	.22	2.3
Old Glatfelter	Pennsylvania	York	55	147	74.3	2	1.69	2.28
Williams Bridge	Pennsylvania	Scranton	48	1,051	5	210	.01	1.5
Fishing Creek	Maryland	Frederick	12	236	8.5	28	.03	.47

1/ Excluding area of lake. 2/ Estimated

the watershed subject to erosion. In order to materially reduce the sediment inflow to these reservoirs, a more extensive erosion control program, therefore, is required. This program would include approved soil and water conservation practices such as contour plowing, strip cropping, terracing, crop rotation, gully control, etc., all of which would increase soil productivity as well as decrease sediment inflow into the reservoirs.

The rate of storage depletion of Loch Raven Reservoir can be reduced somewhat by the establishment of vegetative screens in the Paper Mill and Ashland Pools. Both of these pools have above-crest deposits upon which small patches of willow have become established. If willow, or other vegetation, could be established at this time over areas of above-crest deposits which do not have them now, a vegetative screen could be developed which would reduce the velocity of the flood water entering the pools and cause it to drop part of its sediment load in the pools rather than carry it down into the reservoir. By this method, above-crest deposits could be built up more rapidly and the sediment restrained from entering the reservoir and reducing active storage space. This is a natural process, but if speeded up it may add a number of years to the life of the reservoir.

An effective barrier could be established by cutting willow saplings and sticking them into the deposits vertically. They root readily and sustain a rapid growth. Cottonwood may be propagated in the same way but requires somewhat higher ground than willow. Grasses, rushes, wildrice, reeds, cane, or swamp bush could be established over those areas which are too wet to sustain willow growth. All of these types of vegetation, when once established, spread rapidly and form a dense vegetative screen. They may be obtained at little cost from nearby swamp areas and at the outer margins of the pools themselves.

Figure 1

MAP OF LOCH RAVEN RESERVOIR
BALTIMORE, MD.

R2 —— R1 = Range on which sediment measurements were made.
October 4 - 5, 1943.

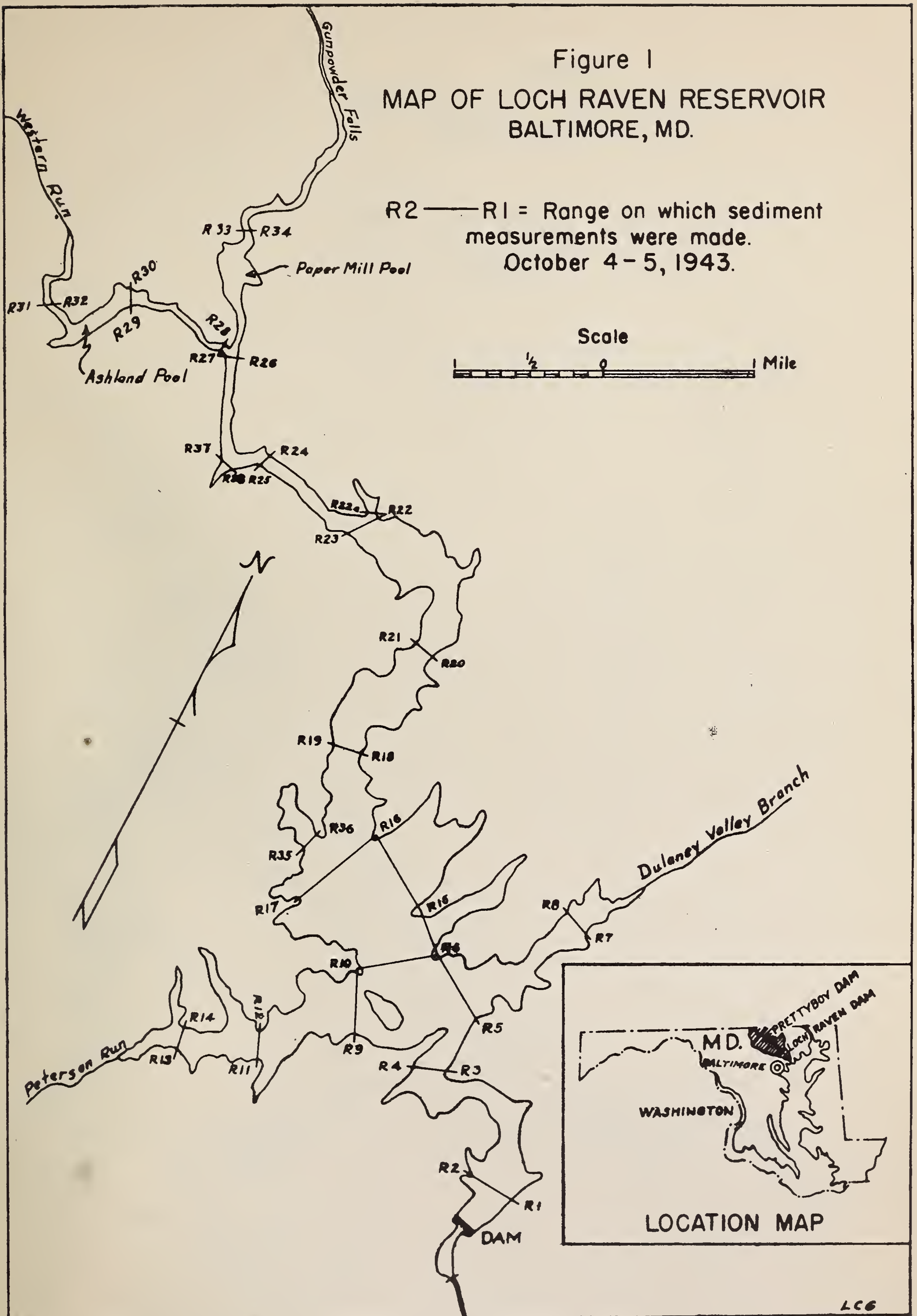
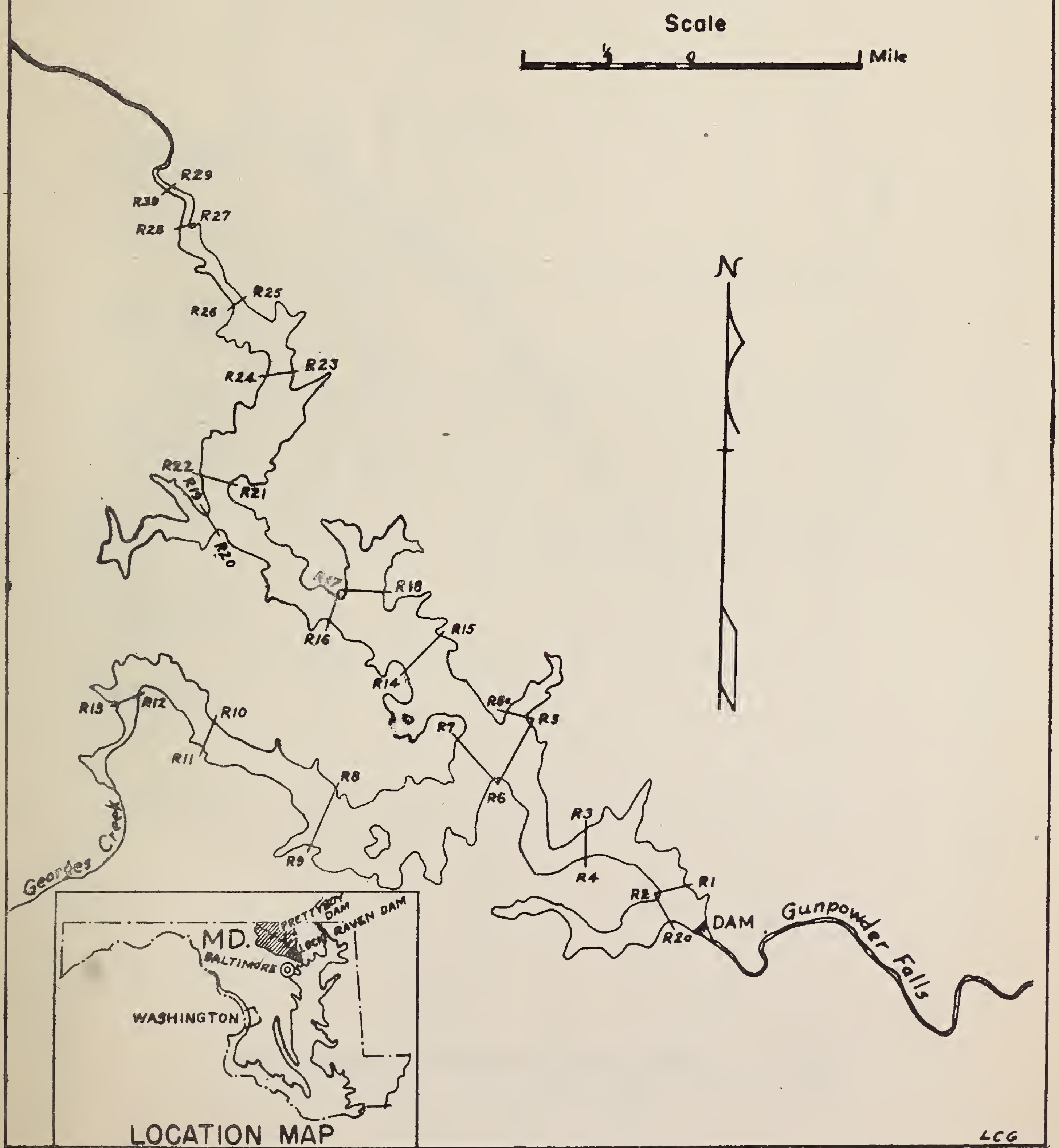


Figure 2

MAP OF PRETTYBOY RESERVOIR
NEAR BALTIMORE, MD.

R2 —— R1 = Range on which sediment measurements were made October 6–7, 1943.



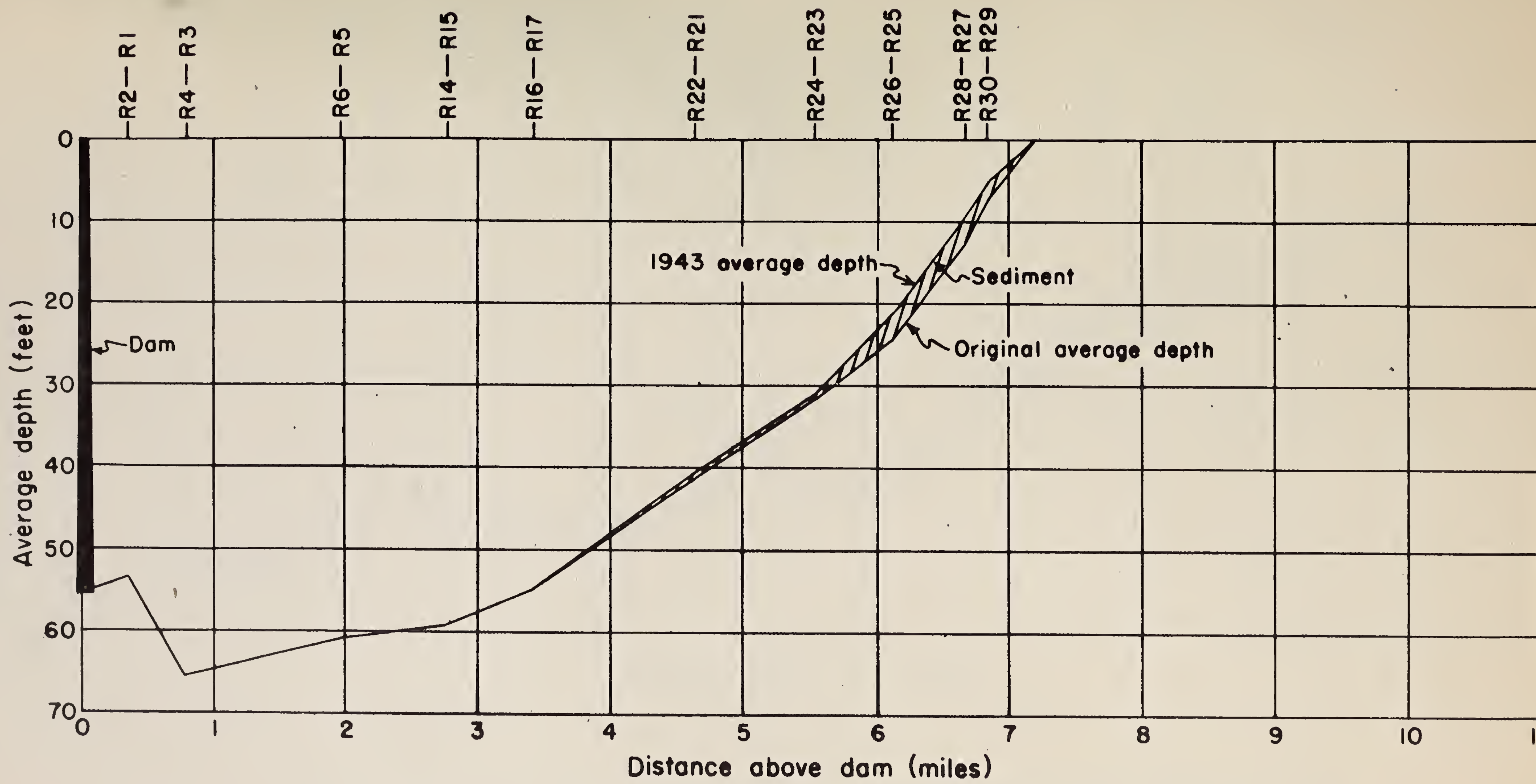


Figure 3: Distribution of sediment in Prettyboy Reservoir. Baltimore, Md.

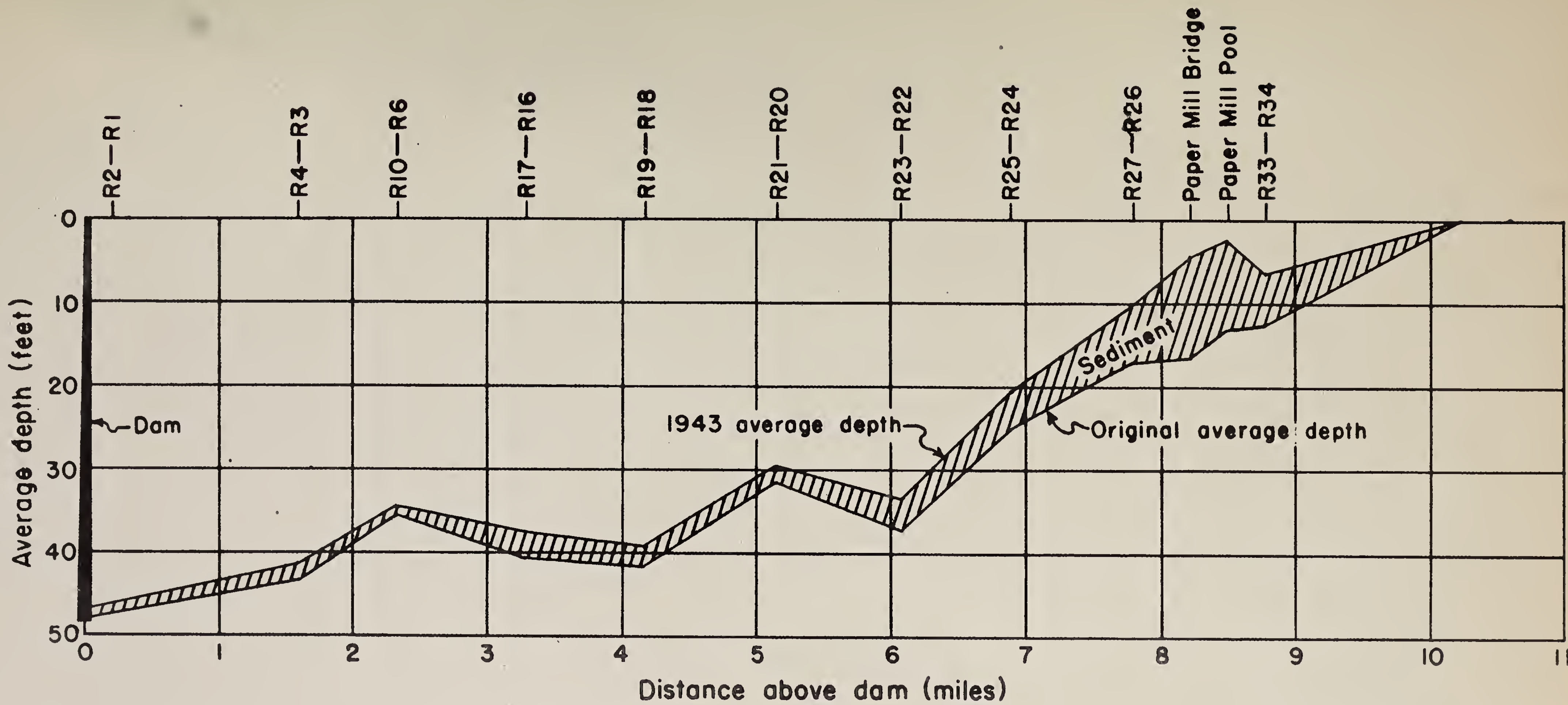


Figure 4: Distribution of sediment in Loch Raven Reservoir. Baltimore, Md.